THE DISTRIBUTION OF COPPER, LEAD, AND ZINC IN THE SEDIMENT AND WATER OF LAKE CARL BLACKWELL, OKLAHOMA

By

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PREFACE

The objectives of this study were to (1) compare the concentration of three heavy metals in the sediment and water of deep, relatively undisturbed areas of Lake Carl Blackwell with shallow areas having well circulated water, (2) determine if heavy metal distribution was changed following strong wind or rain, and (3) determine vertical distribution of heavy metals in the sediment and the water.

Dr. Jerry Wilhm served as the Committee Chairman, directed the research, and supplied valuable moral support. Dr. Troy Dorris served on the advisory committee and provided research equipment for the field work. Dr. Ronal McNew also served on the advisory committee and provided considerable assistance with statistical analyses. Dr. Serling Burks suggested heavy metal analysis techniques and furnished laboratory research facilities. I am very grateful for the assistance they provided.

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CHAPTER I

INTRODUCTION

Heavy metals have a density greater than five. These metals combine with a variety of organic molecules and are powerful enzyme inhibitors because of their interactions with ligands present in most proteins (Pringle et al. 1968). Passow, Rothstein, and Clarkson (1961) characterized heavy metals as "a group of toxic agents possessing universal reactivity yet individual specificity".

Heavy metals have been accumulating for years in sediments, water, and biota of lakes and streams. Lucas et al. (1970) stated that "trace contaminants may have effects on the ecosystem as great or greater than those of the more common pollutants". Six heavy metals have been found frequently in the aquatic areas of this region (personal communication, Gordon Wallace). Four of these metals, copper, chromium, lead, and zinc, have been classified as having a "very high pollution potential"(Bowen 1966).

The distribution of trace metals in estuarine sediment, water, and biota is governed by (1) the chemical and physical state of the metals, (2) the chemical and physical state of the environment and, (3) the affinity of these metals for concentration by aquatic organisms or adsorption on particulate matter (Cross et al. 1970). Distribution of metals in a freshwater reservoir is probably governed by similar mechanisms. When sediment becomes suspended by turbulence,

an increased opportunity exists for particulate matter and water to exchange and redistribute trace metals. In lakes where currents are strong, this phenomenon is probably quite important in the distribution of metals.

Metals may be in a chemical or physical state that makes exchange with other components of the environment impossible. Changes in pH, dissolved oxygen, temperature, etc. which may influence the rate of exchange between sediment and water may not affect elements that are tightly bound to sediments or to dissolved organic compounds. Therefore it is important to consider the portion of these metals which are available for cycling within the system. Various researchers (Nriagu 1967, Riemer and Toth 1970, Cross et al. 1970, and John et al. 1972) have measured the acid-extractable fraction of metals in the sediment as a gross estimate of the amount of element which may be available for exchange.

Heavy metals and salts of heavy metals are found in many agricultural runoffs and industrial wastes. Lake Carl Blackwell is a man-made impoundment which receives runoff primarily from natural and agricultural sources. No information is available about the metal content of the various components of the lake. The objectives of this study were to (1) compare the concentration of three heavy metals in the sediment and water of deep, relatively undisturbed areas of Lake Carl Blackwell with shallow areas having well circulated water, (2) determine if heavy metal distribution is changed following strong wind or rain, and (3) determine verticle distribution of heavy metals in the sediment and water. The following hypotheses were tested:

H_o : there is no difference in concentration of metals in the water between two areas of the lake: deep, relatively undisturbed water and shallow, well circulated water.

H_o : there is no difference in metal content of water collected at the surface and water at the sediment-interface.

H_o : there is no difference in concentration of metals in the water over time.

H_o : there is no difference in acid-extracted metal content of the sediment between two areas of the lake: deep, relatively undisturbed water and shallow, well circulated water.

H_o : there is no difference in the distribution of metals in the sediment over time.

H_o : there is no difference in metal content of the sediment over depth of the sediment.

CHAPTER II

REVIEW OF RELATED LITERATURE

Few people were concerned about heavy metals accumulating in rivers and lakes until recently. From 1953 to 1960, 110 persons died or were severely disabled after eating fish and shellfish containing mercury caught in Minamata Bay, Japan (Konrad 1971). In 1970 fish taken from Lake St Clair, Canada, contained concentrations of mercury as high as 5 ug/g or ten times the action level established by the Federal Drug Administration. Although the effects of other metals have not been as dramatic, they continue to accumulate in the sediment and biota of lakes and streams.

Metals may accumulate in sediments to many times the levels found in overlying waters (Table I). The concentration of copper was 102 ug/g in the sediment of Tasman Bay, New Zealand, but only 2 ug/l in the seawater (Brooks and Rumsby 1965). The concentration of iron in the sediment of Tasman Bay was 73,000 ug/g and 10 ug/l in the seawater. The iron content of Lake Mendota, Wisconsin, water was 100 ug/l, while concentrations in the sediment reached 16.8 ug/g (Nriagu 1967). Delfino et al. (1969) observed a maximum level of iron in Lake Mendota sediments of 26.7 ug/g. The concentration of zinc in the Newport River estuary was 0.6 ug/l and 0.6 ug/g in the water and sediment, respectively (Cross et al. 1970). The levels of iron were 39 ug/l in the water and 11 ug/g in the sediment.

Water of the Illinois River contained 1.1 ug/l copper and the sediment contained 19 ug/g (Mathis and Cummings 1971). The concentration of lead was 2 ug/l in the water and 28 ug/g in the sediment. In various Wisconsin rivers the maximum concentrations of mercury were 648 ug/g in the sediment and 6 ug/l in the water (Konrad 1971). Background levels of mercury in the sediment due to natural sources ranged from .05 to 0.35 ug/g with a mean of 0.15 ug/g. Iron and magnesium contents of the sediment from the Experimental Lakes, Canada were 41,500 and 4,700 ug/g (by ash weight), respectively (Brunskill et al. 1971). The water contained 50 ug/l iron and 900 ug/l magnesium (Armstrong and Schindler 1971).

The concentration of metals in sediments generally decreases with depth. In sediment from Esthwaite in the English Lake District iron content decreased from 83,000 to 48,000 ug/g in the first 5 cm (Gorham 1964). Manganese content decreased from 13,000 to 800 ug/g in the same interval. Manganese content was two to five times higher in the surface sediments than in deeper layers at all locations sampled in Lakes Michigan and Superior. (Callender 1969) In two cores taken in Lake Michigan, zinc concentration in the sediment decreased 140 ug/g in the first 6 cm (Shimp et al. 1970). Lead content of the sediment decreased 70 ug/g in the same interval. Arsenic content of Lake Michigan sediment decreased from 30 to 6 ug/g in the first 10 cm (Shimp et al. 1971). The level of copper decreased in the first 8 cm from 50 to 20 ug/g. Lead and chromium showed decreases of approximately the same magnitude as copper. Iron content in Lake Trout, Wisconsin, was 66,000 ug/g in the surface sediment and 45,000 ug/g in sediment from a depth of 20 cm (Bartleson 1971). In contrast to the above, magnesium content of surface sediments

in Lake Michigan was less than the content in deeper layers (Callender 1969). Arsenic concentration increased as much as 40 ug/g in the first 10 cm in some cores taken from Lake Michigan (Ruch et al. 1970). The preceding examples show that investigation of vertical distribution is essential in a study of heavy metal content of bottom sediments.

TABLE I

COPPER, LEAD, AND ZINC IN WATER AND SEDIMENTS
AS REPORTED IN THE LITERATURE

Water (ug/l)	Sediment (ug/g)	Locale	Source
		Copper	
3	-	seawater	Goldberg (1957)
-	102	Tasman Bay, New Zealand	Brooks and Rumsby (1965)
1.2	-	170 High Sierra Lakes	Bradford et al. (1968)
5.2	-	Minnesota	Bright (1968)
66	-	Monongahela River	Kopp and Kroner (1968)
15	-	Lake Erie	Chawla and Chua (1969)
3	-	Puerto Rico	Martin (1970)
-	39	Lake Michigan	Shimp et al. (1970)
1.1	19	Illinois River	Mathis and Cummings (1971)
-	30	Lake Michigan	Shimp et al. (1971)
10	10	Mississippi River	Morris et al. (1972)
5	11.8	Lake Carl Blackwell	Present study
		Lead	
3	-	seawater	Goldberg (1957)
-	5	Tasman Bay, New Zealand	Brooks and Rumsby (1965)
0.5	-	170 High Sierra Lakes	Bradford et al. (1968)
56	-	Ohio River	Kopp and Kroner (1968)
4	-	Lake Erie	Chawla and Chua (1969)
-	27	Lake Michigan	Shimp et al. (1970)
2	28	Illinois River	Mathis and Cummings (1971)
-	48	Lake Michigan	Shimp et al. (1971)
10	14	Mississippi River	Morris et al. (1972)
3	25.0	Lake Carl Blackwell	Present study

TABLE I (Continued)

		Zinc	
116-332	-	Saale River, Germany	Heide and Singer (1954)
10	-	seawater	Goldberg (1957)
7	10-18	Redfish Bay, Texas	Parker (1962)
38	400	Potomac River	O'Connor et al. (1964)
1.5	-	170 High Sierra Lakes	Bradford et al. (1968)
8	-	Lake Erie	Chawla and Chua (1969)
0.6	0.6	Newport River Estuary	Cross et al. (1970)
-	84	Lake Michigan	Shimp et al. (1970)
-	70*	Experimental Lakes Area, Canada	Brunskill et al. (1971)
-	119	Lake Michigan	Shimp et al. (1971)
10	79	Mississippi River	Morris et al. (1972)
20	42.1	Lake Carl Blackwell	Present study

* -by ash weight.

CHAPTER III

DESCRIPTION OF LAKE CARL BLACKWELL

Lake Carl Blackwell is located in Payne County, 11 km west of Stillwater, Oklahoma, on state highway 51C. Construction of the earth-and-rockfill dam started in 1936 as a project of the Works Progress Administration by damming Stillwater Creek at Section 10, Township 19N, Range 1E. After completion of the dam in 1937, the basin began filling and reached spillway level at an elevation of 287.8 m MSL in 1945. Originally designed for recreational purposes, it now also serves as the water supply for the city of Stillwater. The reservoir last reached maximum capacity of approximately 80 million m^3 and maximum surface area of 1500 ha in 1961. On June 1, 1972, the lake was 5.4 m below spillway level, approximately 5.9 km long and 3.6 km at the widest point. Mean depth was 3 m.

The main body of the reservoir is oriented in an east-west direction and at right angles to the prevailing southerly winds. Several shallow arms extend north and south. Because of the shallow depth of the lake and the low unprotected surrounding areas, the wind induced currents keep the lake water circulated and turbid. Due to this mixing, verticle variation in physical and chemical conditions is slight. Thermal stratification and associated oxygen depletion occur only during irregular summer

periods of high temperature and decreased wind velocity. Then stratification is limited to the main pool near the dam on the east end of the lake and to the original stream channels of the main reservoir and major coves.

The reservoir's flood plain is relatively level with few irregularities except the former stream channel which lies 1-3 m below the plain. The drainage basin, part of the Cimarron River Basin, is 172.2 km^2 and lies in the Redbed Plains. The soils of the region were derived from red Permain clays and shale. The area has weathered into gently rolling hills covered with pastures of native grasses and wooded areas. The majority of the land surrounding the reservoir is owned by Oklahoma State University and is leased for grazing purposes. Most of the privately owned land in the region is also used for grazing though a small amount of wheat and sorgum farming is conducted. Although no extensive farming occurs in the area, runoff from the intermittent Stillwater Creek is highly turbid.

Meteorological data for the sampling period was obtained from the Lake Carl Blackwell Hydrology Laboratory and are presented in Table II.

TABLE II

METEOROLOGICAL DATA FROM LAKE CARL BLACKWELL

Date	Rainfall (cm)	Wind		
		Predominant Direction	Mean Daily Velocity (km/h)	Maximum Hourly Velocity (km/h)
9/8/72	0.61	NE	8.5	11
9/9/72*	2.79	NE	9.3	11
9/10/72	0	SE	9.3	13
9/11/72	1.30	SE	8.0	13
9/12/72	0	S	9.8	13
9/13/72	0	SW	13.8	18
9/14/72*	0	NE	10.1	14
9/24/72	0	SW	16.5	24
9/25/72	0	SW	14.6	21
9/26/72*	0	NE	7.5	14
9/27/72	0	SE	8.0	13
9/28/72	0.41	SW	12.0	21
9/29/72	0	NE	12.0	18
9/30/72*	0	SW	8.2	11
10/1/72	0	SW	8.2	14
10/2/72	0	S	11.8	14
10/3/72	0	SW	7.7	18
10/4/72	0	E	4.2	8
10/5/72	0	S	8.3	10
10/6/72	0.08	N	16.3	22
10/7/72*	0	NE	5.0	10

* -indicates sampling dates

CHAPTER IV

EXPERIMENTAL DESIGN

Comparison of metal concentrations in the water and sediment over five time periods at seven stations located in Lake Carl Blackwell were made with an analysis of variance. Water samples were collected from the surface and the water-sediment interface. The A.O.V. for variation in the concentration of any one metal in the water is as follows:

SOURCE	Degrees of freedom
Station	6 (s-1)
Time	4 (t-1)
Station X Time	24 (s-1)(t-1)
Depth	1 (d-1)
Station X Depth	6 (s-1)(d-1)
Time X Depth	4 (t-1)(d-1)
Station X Time X Depth	24 (s-1)(t-1)(d-1)
Total	69

"Station X Time X Depth" was used as the error term to test for variability due to all of the sources.

Each sediment core was cut into at least five layers. If a core was longer, additional layers were cut from it but these were not included in the A.O.V. The A.O.V. for variation in the

concentration of any one metal in the sediment is as follows:

SOURCE	Degrees of freedom
Station	6 (s-1)
Time	4 (t-1)
Station X Time	24 (s-1)(t-1)
Depth	4 (d-1)
Station X Depth	24 (s-1)(d-1)
Time X Depth	16 (t-1)(d-1)
Station X Time X Depth	96 (s-1)(t-1)(d-1)
Core (Station Time)	35 (d-1)((s)(t))
Core X Depth (Station Time)	140 (c-1)(d-1) ((s)(t))
Total	349

"Core" was used as the error term to test for variability due to "Station", "Time", and "Station X Time" interaction. "Core X Depth" was used as the error term to test for variability due to the other sources. Analyses were performed by computer using the Statistical Analysis System (S.A.S.) Program.

Further statistical analysis consisted of comparing means with a "t" test. The error term computed in the A.O.V. was used to estimate the variance. In this manner any station or group of stations could be compared with any other station or group of stations to determine if the means were stastically different. Similarily, the means of different times or of different depths could be compared.

CHAPTER V

METHODS

Field Methods

Sediment and water samples were collected on five dates: 9, 14, 26, and 30 September and 7 October 1972. Two sediment samples were obtained at each of seven stations. Water depth at stations I, II, and III ranged from 4.0 to 8.5 m. All were greater than the mean lake depth. The bottom was relatively undisturbed. Water depth at each of the remaining stations was less than 2.5 m and the bottom was well circulated by wind induced currents. Figure 1 shows the location of the sampling stations on the lake.

Sediment samples were taken with a vertical core sampler produced by the G.M. Manufacturing & Instrument Co. The sampler was equipped with a 3 X 60 cm polyethylene insert. The sampler was inserted vertically into the sediment and upon retrieval, the insert was removed and the ends sealed with rubber stoppers. All inserts were later frozen until analyses were made.

Water samples were taken at each station from the surface and from the sediment-interface with a Van Dorn water bottle. A 250 ml sample was withdrawn, placed in a polyethylene bottle, and acidified with 2 ml of concentrated nitric acid. The pH of the water was thus kept below 2 to prevent altering the metal content of the

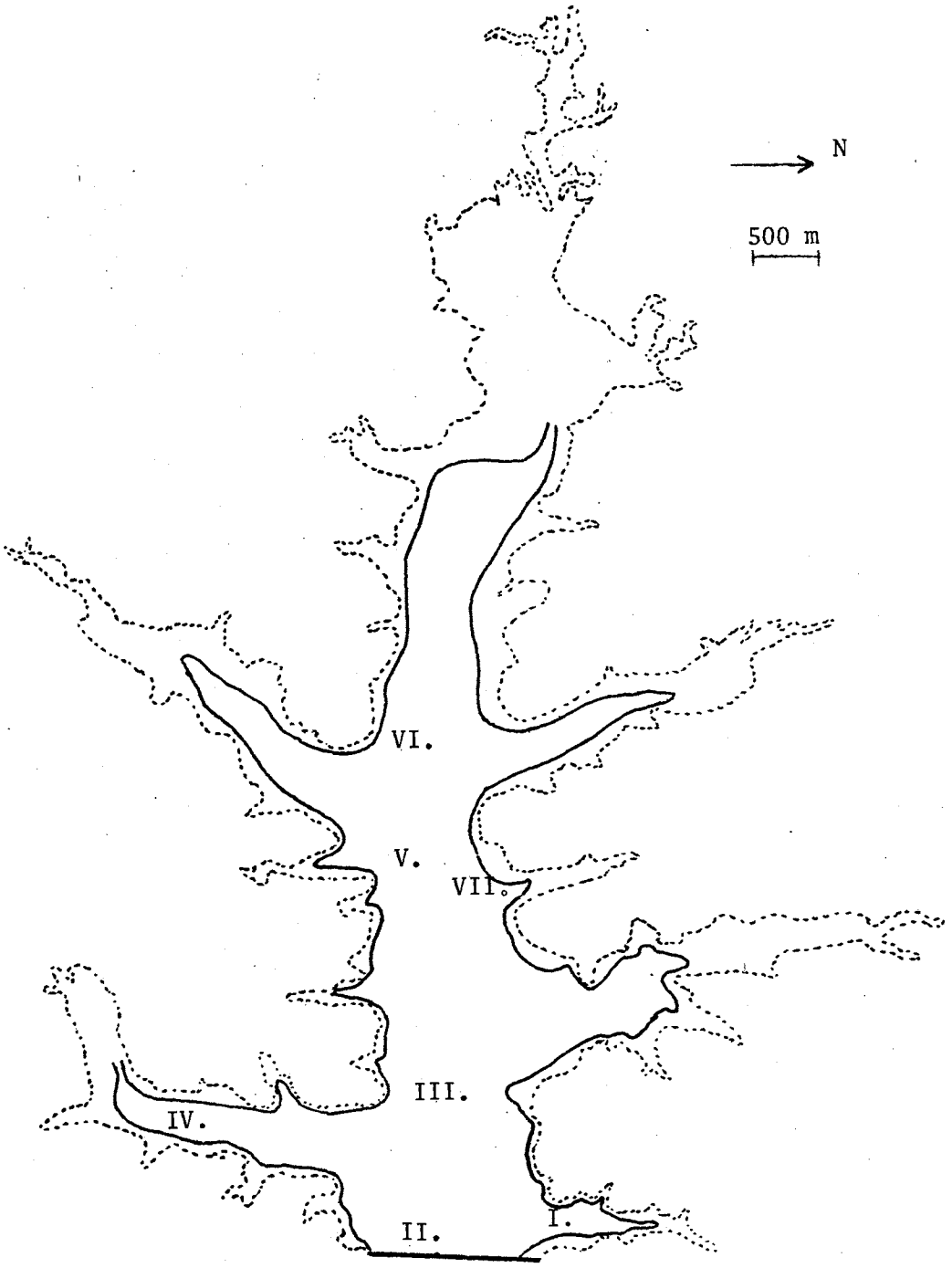

Figure 1. Location of sampling stations on Lake Carl Blackwell.

sample.

Laboratory Methods

Each frozen sediment core was cut into as many of the following layers as its length would permit: 0-1, 2-3, 4-5, 9-10, 14-15, 19-20, 29-30, 39-40, and 49-50 cm. Similar designs were used by Shimp et al. (1970), Ruch et al. (1970), and Shimp et al. (1971). Approximately 5 g of each layer was placed in a tared 200 ml polyethylene flask. The sediment sample was dried in an oven for 12 h at 105 C, placed in a desiccator for 1 h, and then reweighed. Fifty ml of 1 N nitric acid were added to each flask. The flasks were then shaken for 12 h on an Eberback shaker. The above procedure was modified from Nriagu (1967), Reimer and Toth (1970), and John et al. (1972). The flasks were undisturbed for 24 h to permit sedimentation. The liquid was aspirated into a Varian Techtron flame atomic absorption spectrophotometer and analyzed for the presence of copper, lead, and zinc. Absorbance values recorded from the spectrophotometer were compared to a curve of standard concentrations for calculation of the metal content of the liquid. A hydrogen continuum spectrum lamp was used to correct for background interference. Final calculation of metal content of the sediment was done using the equation,

$$\text{metal in solution (mg/l)} \times \frac{50 \text{ ml}}{\text{sample wt (g)}} = \text{metal in sediment (ug/g)}$$

Water samples were analyzed for metal content with a Perkin-Elmer heated graphite atomizer (HGA-70) attachment to the atomic absorption spectrophotometer. A 20 ul sample was pipetted into

the carbon rod of the graphite atomizer. During atomization of the sample the resultant absorbance peak was recorded on a Beckman recorder. If contamination of the pipette was suspected and an unusually high peak recorded, the injections were repeated until two peaks of the same height were observed. Corrections for background interference were made with a hydrogen continuum spectrum lamp. Final calculations of metal concentrations were made by comparing the recorded peak heights to a curve of standard concentrations. The time and temperature regime used for each metal is given in Table III.

TABLE III

THE TIME AND TEMPERATURE REGIMES USED WITH
THE HEATED GRAPHITE ATOMIZER

Metal	Drying		Thermal Decomposition		Atomization	
	Time (sec)	Temp (C)	Time (sec)	Temp (C)	Time (sec)	Temp (C)
Copper	40	95	60	1000	20	2400
Lead	40	95	60	470	20	2400
Zinc	40	95	60	470	20	1800

CHAPTER VI

RESULTS

Copper, Lead, and Zinc in Water

The concentration of copper in the water was relatively uniform at all stations. The range of mean concentrations was from 4 ug/l at stations IV and V to 6 ug/l at stations II, VI, and VII (Table IV). Mean copper content of both the deep water and shallow water stations was 5 ug/l. The null hypothesis of no difference in copper content of the water between shallow and deep water areas of the lake was not rejected.

Variation existed between the copper content of surface water and water collected at the sediment-interface (Table IV). Station II had the largest range, a surface water concentration of 2 ug/l and an interface water concentration of 17 ug/l. At stations IV and VII both the surface and interface water concentrations were 4 ug/l. Overall mean copper concentration of surface water was 4 ug/l and of interface water 6 ug/l (Table V). This variation was statistically significant at the 0.01 level. Thus, the null hypothesis, of no difference between copper concentration of surface water and interface water was rejected.

Temporal variation in copper content of the water over time was statistically signficant ($p = 0.05$). Highest overall mean concentrations were on 9 September and 14 September. Lake Carl

TABLE IV

CONCENTRATION OF METALS IN SURFACE AND BOTTOM WATER OVER FIVE TIME PERIODS AT SEVEN STATIONS IN LAKE CARL BLACKWELL

Station	Date	Copper		Lead		Zinc	
		Surface	Bottom	Surface	Bottom	Surface	Bottom
I	9/9	2	3	1	5	3	35
(6.5)	9/14	3	11	2	5	7	45
	9/26	10	4	2	2	8	10
	9/30	3	6	2	5	4	37
	10/7	5	6	2	3	3	22
	$\bar{x}$	5		3		3	
II	9/9	3	13	2	8	10	97
(8.5)	9/14	2	17	1	4	22	39
	9/26	8	3	2	2	4	14
	9/30	3	4	2	2	4	12
	10/7	2	6	2	2	5	28
	$\bar{x}$	6		3		24	
III	9/9	2	10	2	4	3	36
(4.0)	9/14	10	5	2	3	16	20
	9/26	3	4	2	2	4	5
	9/30	3	5	2	3	4	8
	10/7	3	5	1	3	7	32
	$\bar{x}$	5		2		14	
IV	9/9	4	4	1	4	15	17
(2.0	9/14	5	5	2	3	40	45
	9/26	2	3	2	2	4	9
	9/30	2	8	2	3	8	8
	10/7	2	6	2	2	9	40
	$\bar{x}$	4		2		20	
V	9/9	2	5	2	7	4	63
(2.5)	9/14	4	6	2	3	20	30
	9/26	2	3	2	1	4	7
	9/30	3	3	1	2	3	14
	10/7	2	8	2	4	7	24
	$\bar{x}$	4		3		18	
VI	9/9	3	5	3	7	20	85
(1.5)	9/14	8	6	3	4	42	32
	9/26	2	5	2	3	8	21
	9/30	5	6	2	4	4	35
	10/7	10	8	2	2	2	8
	$\bar{x}$	6		3		19	

TABLE IV (Continued)

VII	9/9	4	17	1	6	10	88
(1.5)	9/14	13	4	2	2	28	16
	9/26	2	3	2	2	10	8
	9/30	4	4	1	2	3	6
	10/7	5	6	1	3	12	13
	$\bar{x}$	6		2		19	

* -depth of the station in meters.

Blackwell received 3.40 cm of rain on 8 and 9 September. This indicates that runoff may have contributed to the copper content of the water. Low mean concentrations of 4 ug/l occurred on 26 and 30 September after periods of low rainfall. The null hypothesis of no difference in copper content of the water over time was rejected.

Little variation existed in lead concentration of the water among the seven stations. Mean concentration at stations III, IV, and VII was 2 ug/l while at the remaining stations it was 3 ug/l (Table IV). A mean concentration of 3 ug/l was observed at both deep water and shallow water stations. Therefore, the null hypothesis, of no difference in lead concentration of the water between two areas of the lake was not rejected.

The variation that existed between lead content of the water and sediment-interface water was small but statistically significant. Mean concentration of the surface water was 2 ug/l and of interface water, 3 ug/l (Table V). On 8 of 35 observations the lead concentrations in the surface and interface water were the same (Table IV). The largest range occurred at station II: surface, 2 ug/l and interface, 8 ug/l. At only one time did the concentration of lead in the surface water exceed that of interface water. Thus, the null hypothesis, of no difference between lead concentration of the surface water and sediment-interface water was rejected.

The variation that existed in the lead content of water over time was statistically significant. The means for each day were compared with a "t" test. The mean concentrations on 9 September

TABLE V

METAL CONCENTRATIONS OF WATER AT THE SURFACE AND SEDIMENT INTERFACE OVERALL TIME PERIODS AND STATIONS

Water Depth	Cu(ug/1)	Pb(ug/1)	Zn(ug/1)
Surface	4	2	10
Interface	6	3	29
F_{cal}	7.57	38.17	27.05
F_{tab}	7.10	7.10	7.10

and 14 September were statistically higher than the mean concentrations of other days. The mean concentrations of the other days were not statistically different from each other. Since Lake Carl Blackwell received rainfall on 8 and 9 September, runoff may have contributed to the lead in the lake. The null hypothesis of no difference in lead content of the water over time was rejected.

Considerable variation existed in the zinc content of the water among seven stations. The lowest and the highest mean concentrations were both from deep water stations, 14 ug/l at station III and 24 ug/l at station II (Table IV). The mean concentration of the deep water stations, 18 ug/l was not statistically different than the mean concentration of shallow water stations, 21 ug/l. Thus, the null hypothesis, of no difference in zinc concentration of the water between two areas of the lake was not rejected.

Considerable variation in zinc content of the water existed between surface water and sediment-interface water. The largest range was from 10 ug/l at the surface to 97 ug/l at the interface at station II (Table IV). Four ug/l was measured at both the surface and interface at station IV. The zinc content of surface water exceeded that of interface water on only one of 35 observations. Overall mean concentration of the surface water, 10 ug/l (Table V), was statistically different than the mean concentration of interface water, 29 ug/l. The null hypothesis of no difference between zinc concentrations of surface water and sediment-interface water was rejected.

Significant variation (p = 0.01) existed over time in the zinc concentrations of the water. Means of each day were compared with a "t" test. The highest means, 35 ug/l on 9 September and 29 ug/l on 14 September were statistically different than the means of other days. However, the means of 9 and 14 September were not statistically different, nor were the means of other days different from each other. The lowest mean concentration was 8 ug/l on 26 September. The null hypothesis of no difference in zinc content of the water over time was rejected.

Copper, Lead, and Zinc in Sediment

Considerable variation existed in copper content of sediment among seven stations. The overall mean concentrations varied from 5.2 ug/g at station VII to 16.5 ug/g at station II (Table VI). Deep water stations generally had higher concentrations than shallow water stations. The mean of the deep water stations was 12.9 ug/g and of shallow water stations 10.1 ug/g. The means were statistically different at the 0.01 level and the null hypothesis of no difference in copper content of the sediments between deep and shallow water areas of the lake was rejected.

Although temporal variation in copper content was erratic, the maximum concentration was generally measured during the first three time periods and the minimum concentration during the last two (Table VI). Temporal variation was less than 5 ug/g at all stations except station III. The overall mean concentration varied from 9.3 ug/g on 30 September to 12.9 ug/g on 14 September. The maximum was measured 5 days after the area

TABLE VI

COPPER CONCENTRATIONS IN THE FIRST 15 CM OF LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)*	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	0-1	15.8**	13.7	15.9	11.7	12.4	13.9
	2-3	14.9	14.4	15.1	11.2	11.3	13.4
	4-5	15.3	13.6	13.4	10.1	12.3	13.0
	9-10	15.1	14.9	15.2	12.3	15.3	14.6
	14-15	15.0	15.4	15.1	14.4	15.6	15.1
	$\bar{x}$	15.2	14.4	14.9	12.0	13.4	14.0
II	0-1	14.7	18.4	17.9	15.9	18.1	17.0
	2-3	14.9	17.7	17.3	15.5	17.8	16.6
	4-5	14.6	16.2	16.2	15.7	19.1	16.4
	9-10	15.4	17.0	15.8	14.9	17.5	16.1
	14-15	15.5	16.4	17.9	15.8	15.4	16.2
	$\bar{x}$	15.0	17.2	17.0	15.5	17.6	16.5
III	0-1	6.1	17.4	11.8	6.2	6.9	9.7
	2-3	4.3	15.3	12.5	4.1	5.5	8.4
	4-5	3.5	15.5	13.0	3.9	7.3	8.6
	9-10	4.0	16.1	8.0	4.6	3.8	7.3
	14-15	4.3	16.2	10.1	3.4	4.9	7.8
	$\bar{x}$	4.5	16.1	11.1	4.4	5.7	8.3
IV	0-1	13.1	11.7	18.7	9.7	13.0	13.2
	2-3	12.2	12.4	12.7	10.4	11.1	11.7
	4-5	12.5	12.1	12.8	9.9	12.7	12.0
	9-10	13.1	8.8	7.7	7.5	11.5	9.7
	14-15	9.3	5.7	5.6	5.8	8.0	6.9
	$\bar{x}$	12.0	10.1	11.5	8.6	11.3	10.7
V	0-1	12.6	12.7	13.4	10.4	12.2	12.3
	2-3	13.3	13.1	13.4	9.8	14.8	12.9
	4-5	13.0	13.8	13.8	11.2	14.7	13.3
	9-10	13.9	14.5	14.7	8.3	6.4	11.5
	14-15	9.7	7.8	12.5	3.9	5.9	7.9
	$\bar{x}$	12.5	12.4	13.6	8.7	10.8	11.6
VI	0-1	11.5	14.0	14.0	12.0	14.3	13.1
	2-3	11.6	13.4	13.9	11.6	13.4	12.8
	4-5	12.1	15.0	13.3	11.9	14.1	13.3
	9-10	13.0	14.9	13.6	6.2	14.4	12.4
	14-15	10.6	14.6	14.5	12.2	9.4	12.2
	$\bar{x}$	11.8	14.4	13.9	10.8	13.1	12.8

TABLE VI (Continued)

VII	0-1	3.9	5.7	4.9	5.0	5.2	4.9
	2-3	3.9	5.3	5.6	4.9	6.0	5.1
	4-5	3.6	4.2	5.3	4.8	5.5	4.7
	9-10	4.8	5.8	5.8	5.0	5.4	5.4
	14-15	5.7	6.4	6.4	6.7	5.2	6.1
	$\bar{x}$	4.4	5.5	5.6	5.3	5.5	5.2

* -depths 19-50 cm have not been included in the A.O.V. and thus are shown in Appendix A.

** -all values expressed as ug/g dry weight of sediment - each value is the mean of two observations.

received 2.79 cm of rain. This indicates that runoff may have contributed to the copper content of the sediments. The overall mean concentrations on each day were compared with "t" tests and a difference of 1.0 ug/g was statistically significant. All means were different except 9 September and 7 October and the means for 14 September and 26 September. The null hypothesis of no difference in copper content of the sediments over time was rejected.

Copper tended to decrease in concentration with depth at stations II, III, IV, and VI (Table VI). The greatest concentration was found in the deepest layer at stations I and VII and in the 4 to 5 cm layer at station V. Vertical variation exceeded 5 ug/g at stations IV and V and was less than 2.5 ug/g at other stations. The overall mean copper content of the sediment at the water interface was 12.0 ug/g. This was not significantly different from the 2-3 cm layer or the 4-5 cm layer. The 4-5 cm layer was significantly different from the 9-10 cm layer. The mean copper content of the 9-10 cm layer, was significantly different from the 14-15 cm layer. The null hypothesis of no difference in copper content of the sediments over depth was rejected.

The vertical distribution of copper in the sediments was different in shallow water stations than deep water stations (Figure 2). The mean copper content of the shallow water station surface sediments was 10.9 ug/g. The concentration then decreased at a relatively uniform rate to 4.4 ug/g at a depth of 39-40 cm. The mean concentration of surface sediments at deep water stations was 13.5 ug/g. This decreased to 12.6 in the 4-5 cm section and

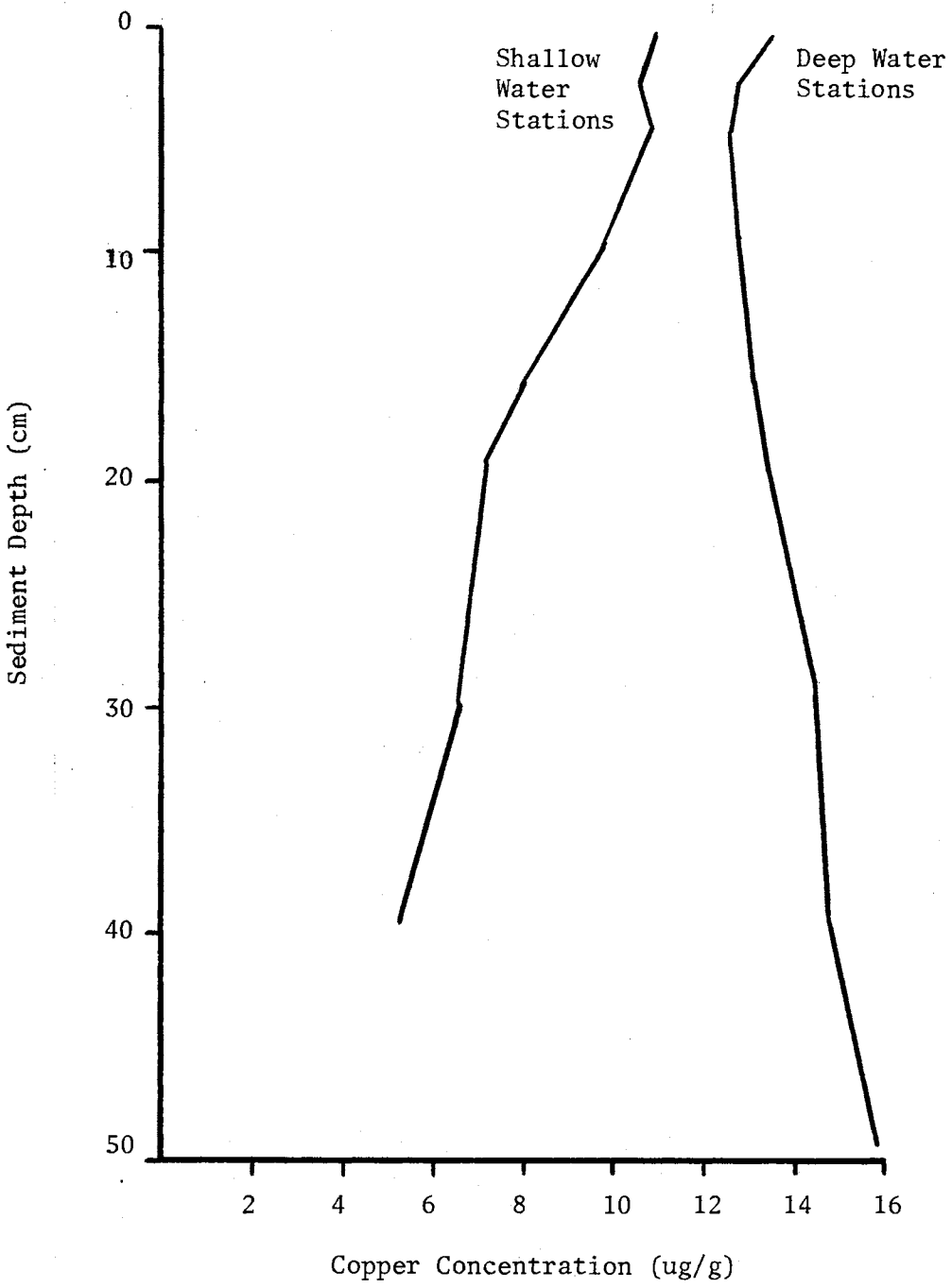

Figure 2. Copper Concentrations in Shallow and Deep Water Sediments in Lake Carl Blackwell.

increased rather uniformly to 15.8 ug/g at 49-50 cm.

Lead content of sediments averaged over all time periods and depths varied from 6.5 ug/g at station VII to 41.4 ug/g at station II (Table VII). The mean of the deep water stations was 30.7 ug/g, while the mean of shallow water stations was 19.5 ug/g. The means were statistically different at the 0.01 level; therefore, the null hypothesis of no difference in the lead content of the sediments between deep water and shallow water areas of the lake was rejected.

The minimum lead concentration was generally measured on 9 September, while the maximum concentration was generally observed during the middle three time periods. Temporal variation was less than 15 ug/g at all stations except station III. Concentrations averaged over all depths at all stations ranged from 20.6 ug/g on 9 September to 28.2 ug/g on 14 September. As with copper, the maximum was measured 5 days after the area received a heavy rain. Thus, it appears that runoff may have contributed to the lead content of the sediments. The overall mean concentrations for each day were compared with "t" tests and a difference of 3.8 ug/g was statistically significant. September 14, 20, and 30 were not different from each other but were different from 9 September and 7 October. September 9 and October 7 were not different from each other. Time was significant in the A.O.V. and the null hypothesis of no difference in the lead content of the sediments over time was rejected.

The maximum mean concentration of lead occurred at a depth of 4-5 cm at stations II, III, IV, and VI(Table VII). The

TABLE VII

LEAD CONCENTRATIONS IN THE FIRST 15 CM OF LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)*	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	0-1	39.2**	34.5	32.8	34.0	26.6	33.4
	2-3	37.3	36.2	34.9	33.6	29.0	34.2
	4-5	35.2	35.7	32.9	29.4	33.0	33.2
	9-10	35.9	37.5	36.7	37.1	31.8	35.8
	14-15	36.4	39.5	35.6	43.2	29.4	36.8
	$\bar{x}$	36.8	36.7	34.6	35.4	30.0	34.7
II	0-1	32.7	43.1	44.3	38.9	36.6	39.1
	2-3	36.2	44.2	46.1	50.5	37.2	42.9
	4-5	32.6	41.9	44.5	53.8	44.6	43.5
	9-10	33.3	42.6	44.2	48.8	35.5	40.9
	14-15	35.4	40.8	40.4	52.4	33.8	40.6
	$\bar{x}$	34.0	42.5	43.9	48.9	37.6	41.4
III	0-1	6.5	34.2	25.4	8.6	8.4	16.6
	2-3	4.8	35.4	28.6	7.4	8.1	16.8
	4-5	5.6	37.0	27.6	7.5	7.0	17.0
	9-10	4.6	40.1	13.5	9.8	5.1	14.6
	14-15	4.9	39.4	16.0	10.2	6.4	15.4
	$\bar{x}$	5.3	37.2	22.2	8.7	7.0	16.1
IV	0-1	26.4	28.5	29.3	30.3	25.5	28.0
	2-3	26.2	30.0	31.8	38.1	28.0	30.8
	4-5	30.1	34.2	35.7	36.0	30.6	33.3
	9-10	27.8	17.1	9.1	22.5	21.7	19.6
	14-15	16.4	8.4	8.3	15.5	8.2	11.4
	$\bar{x}$	25.4	23.6	22.8	28.5	22.8	24.6
V	0-1	19.0	23.0	29.9	27.0	20.4	23.8
	2-3	21.3	28.2	29.6	27.8	27.4	26.9
	4-5	22.3	29.0	28.7	24.8	24.7	25.9
	9-10	20.4	23.9	30.3	15.7	6.4	19.3
	14-15	12.5	7.8	17.2	4.6	5.6	9.5
	$\bar{x}$	19.1	22.4	27.1	20.0	16.9	21.1
VI	0-1	20.1	27.4	29.4	23.1	26.8	25.4
	2-3	16.6	31.1	28.2	27.5	31.7	27.0
	4-5	19.5	29.3	26.5	31.5	31.4	27.7
	9-10	18.7	28.0	26.8	25.4	27.9	25.3
	14-15	17.4	26.4	25.8	30.3	14.5	22.9
	$\bar{x}$	18.5	28.4	27.3	27.6	26.4	25.7

TABLE VII (Continued)

VII	0-1	5.6	6.7	5.6	6.7	6.1	6.2
	2-3	6.0	6.3	6.8	7.8	6.5	6.8
	4-5	5.0	6.6	5.9	7.9	6.8	6.4
	9-10	5.5	6.8	5.8	8.4	5.7	6.5
	14-15	4.8	6.8	6.9	8.6	5.9	6.6
	$\bar{x}$	5.4	6.7	6.2	7.9	6.2	6.5

* -depths 19-50 cm have not been included in the A.O.V. and thus are shown in Appendix A.

** -all values expressed as ug/g dry weight of sediment - each value is the mean of two observations.

maximum concentration was found in the 2-3 cm layer at stations V and VII and in the deepest layer at station I. At stations III, IV, V, and VI the concentration in the deepest layer was less than the concentration at the interface. Vertical variation was 21.9 ug/g at station IV and 17.4 ug/g at station V but was less than 5.0 ug/g at the remaining stations. The mean lead concentration of the sediment at the water interface was 24.6 ug/g. This was statistically different ($p = 0.05$) from the 2-3 cm layer. The 2-3 cm layer and the 4-5 cm layer were not different. The 4-5 cm layer and 9-10 cm layer were different ($p = 0.01$) as were the 9-10 cm and 14-15 cm layer. Depth was significant in the A.O.V. and the null hypothesis of no difference in the lead content of the sediments over depth was rejected.

The vertical distribution of lead in the sediments was different in deep and shallow water stations (Figure 3). The mean concentration of interface sediment at shallow water stations was 20.9 ug/g. The concentration increased to 23.3 ug/g in the 4-5 cm layer and decreased at a relatively constant rate to 4.6 ug/g in the 39-40 cm layer. The concentration of lead in deep water stations was relatively uniform.

Considerable variation existed in the zinc content of sediments among the seven stations (Table VIII). The overall mean concentrations varied from 16.6 ug/g at station III to 66.3 ug/g at station II. The means of the deep water stations, 48.5 ug/g, and shallow water stations, 34.1 ug/g, were statistically different at the 0.01 level and the null hypothesis of no difference in zinc content of the sediments between deep and shallow water areas was rejected.

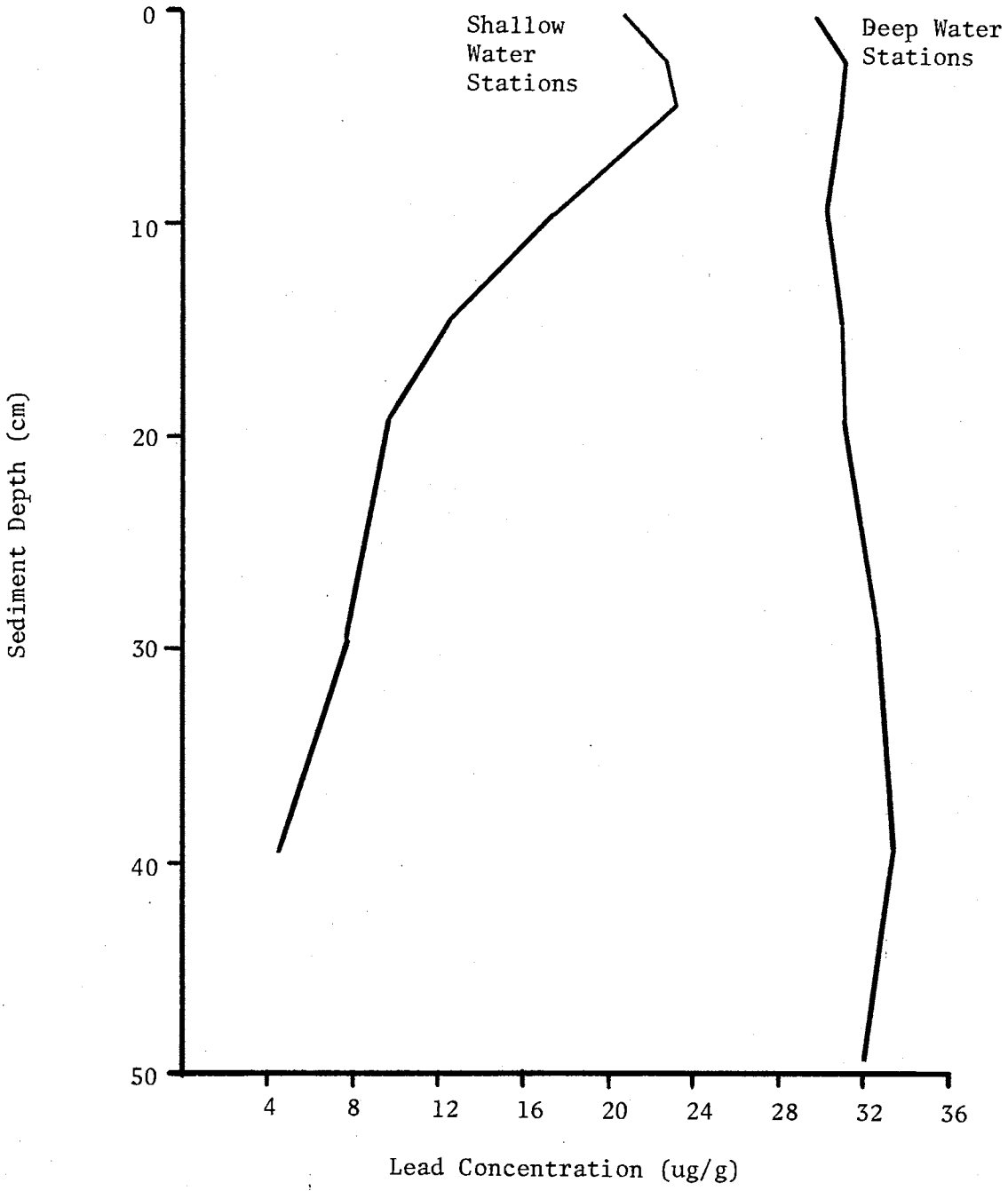

Figure 3. Lead Concentrations in Shallow and Deep Water Sediments in Lake Carl Blackwell.

Considerable variation existed in the zinc content of the sediment over time (Table VIII). Minimum concentrations were generally observed on 9 September and the maximum concentrations during the last three time periods. Temporal variation was less than 13.0 ug/g at all stations except II and III, where the variation was 22.5 and 46.7 ug/g, respectively. Concentrations averaged over all depths at all stations ranged from 34.4 ug/g on 9 September to 43.7 ug/g on 14 September. Similarly, as with copper and lead it appears that runoff following a heavy rain may have contributed to the zinc content of the sediments. The mean concentrations of each day were compared with a "t" test and a difference of 3.9 ug/g was statistically significant. None of the means were different except: 9 September was different from all other days and 14 September was different from 30 September. Time was significant in the A.O.V. and the null hypothesis of no difference in zinc content of the sediments over time was rejected.

Zinc content of the sediments tended to increase with depth at stations I and VII and decrease with depth at station III (Table VIII). At stations IV and V the maximum concentration occurred in the 4-5 cm layer at station VI in the 2-3 cm layer, and at station II in the surface layer. Vertical variation was less than 10.0 ug/g at all stations except at IV and V where the variation exceeded 20.0 ug/g. The overall mean zinc content of the sediment at the water interface was 41.6 ug/g. This was not significantly different ($p = 0.05$) from the 2-3 cm layer. The 2-3 cm layer was not different from the 4-5 cm but the 4-5 cm was different from the 9-10 cm layer. The mean zinc content of

TABLE VIII

ZINC CONCENTRATIONS IN THE FIRST 15 CM OF LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)*	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	0-1	57.8**	46.4	63.7	41.9	43.7	50.7
	2-3	52.7	52.7	56.5	40.3	41.4	48.8
	4-5	53.1	50.6	50.8	38.4	43.3	47.2
	9-10	54.6	51.9	55.6	45.0	50.9	51.6
	14-15	53.4	56.6	55.9	53.8	52.5	54.4
	$\bar{x}$	54.3	51.6	56.5	43.9	46.3	50.5
II	0-1	54.9	61.9	71.1	72.5	78.5	67.8
	2-3	54.7	65.2	66.1	71.6	76.0	66.7
	4-5	53.4	63.3	62.7	71.3	86.1	67.4
	9-10	52.2	62.0	63.4	67.1	74.6	63.9
	14-15	56.6	66.1	65.8	72.3	69.2	66.0
	$\bar{x}$	54.4	63.7	65.8	70.9	76.9	66.3
III	0-1	15.4	60.4	42.3	19.3	24.0	32.3
	2-3	10.4	57.8	47.4	15.7	21.1	30.5
	4-5	10.1	58.8	49.0	15.2	21.0	30.8
	9-10	10.1	57.2	29.5	15.7	13.8	25.3
	14-15	8.6	53.6	35.4	10.5	16.7	25.0
	$\bar{x}$	10.9	57.6	40.7	15.3	19.3	28.8
IV	0-1	37.1	42.1	43.3	47.9	47.4	43.6
	2-3	36.8	42.1	41.6	46.8	45.4	42.5
	4-5	42.2	46.2	44.9	42.9	45.7	44.4
	9-10	29.5	33.8	23.4	35.0	39.8	32.3
	14-15	22.7	17.4	16.8	23.6	21.9	20.5
	$\bar{x}$	33.6	36.3	34.0	39.2	40.0	36.7
V	0-1	35.4	42.3	42.7	44.1	39.2	40.7
	2-3	37.3	44.2	44.1	44.7	50.8	44.2
	4-5	39.3	44.0	45.4	50.5	49.0	45.7
	9-10	39.8	42.0	46.4	34.9	15.9	35.8
	14-15	27.1	22.6	37.5	18.7	18.7	24.9
	$\bar{x}$	35.8	39.0	43.2	38.6	34.7	38.3
VI	0-1	36.9	46.0	44.2	30.5	50.7	41.7
	2-3	41.8	45.6	47.0	58.2	54.2	49.4
	4-5	38.8	43.5	47.3	55.0	50.9	47.1
	9-10	39.2	44.8	46.6	45.0	51.0	45.3
	14-15	29.9	40.9	44.8	55.9	27.8	39.9
	$\bar{x}$	37.3	44.2	46.0	48.9	46.9	44.7

TABLE VIII (Continued)

VII	0-1	12.2	11.3	14.6	17.3	15.6	14.2
	2-3	14.6	12.6	14.6	20.2	16.0	15.6
	4-5	13.6	12.3	18.6	20.9	18.4	16.8
	9-10	13.7	15.6	17.7	22.5	18.1	17.5
	14-15	18.0	14.7	19.9	26.9	18.9	19.7
	$\bar{x}$	14.4	13.4	17.1	21.5	17.4	16.7

* -depths 19-50 cm have not been included in the A.O.V. and thus are shown in Appendix A.

** -all values expressed as ug/g dry weight of sediment - each value is the mean of two observations.

the 9-10 cm was different than the content of the 14-15 cm layer. The null hypothesis of no difference in zinc content of the sediments over depth was rejected.

The vertical distribution of zinc in the sediments was different in shallow water stations than in deep water stations (Figure 4). The mean concentration of surface sediments of shallow water stations was 35.1 ug/g. This increased to 38.5 ug/g in the 4-5 cm layer and then decreased to 18.4 ug/g in the 39-40 cm layer. Vertical variation at deep water stations was considerably less than shallow water stations. The mean content of deep water sediments decreased from 50.3 ug/g at the surface to 46.9 ug/g at a depth of 9-10 cm. The concentration then increased to 54.4 ug/g in the 49-50 cm layer.

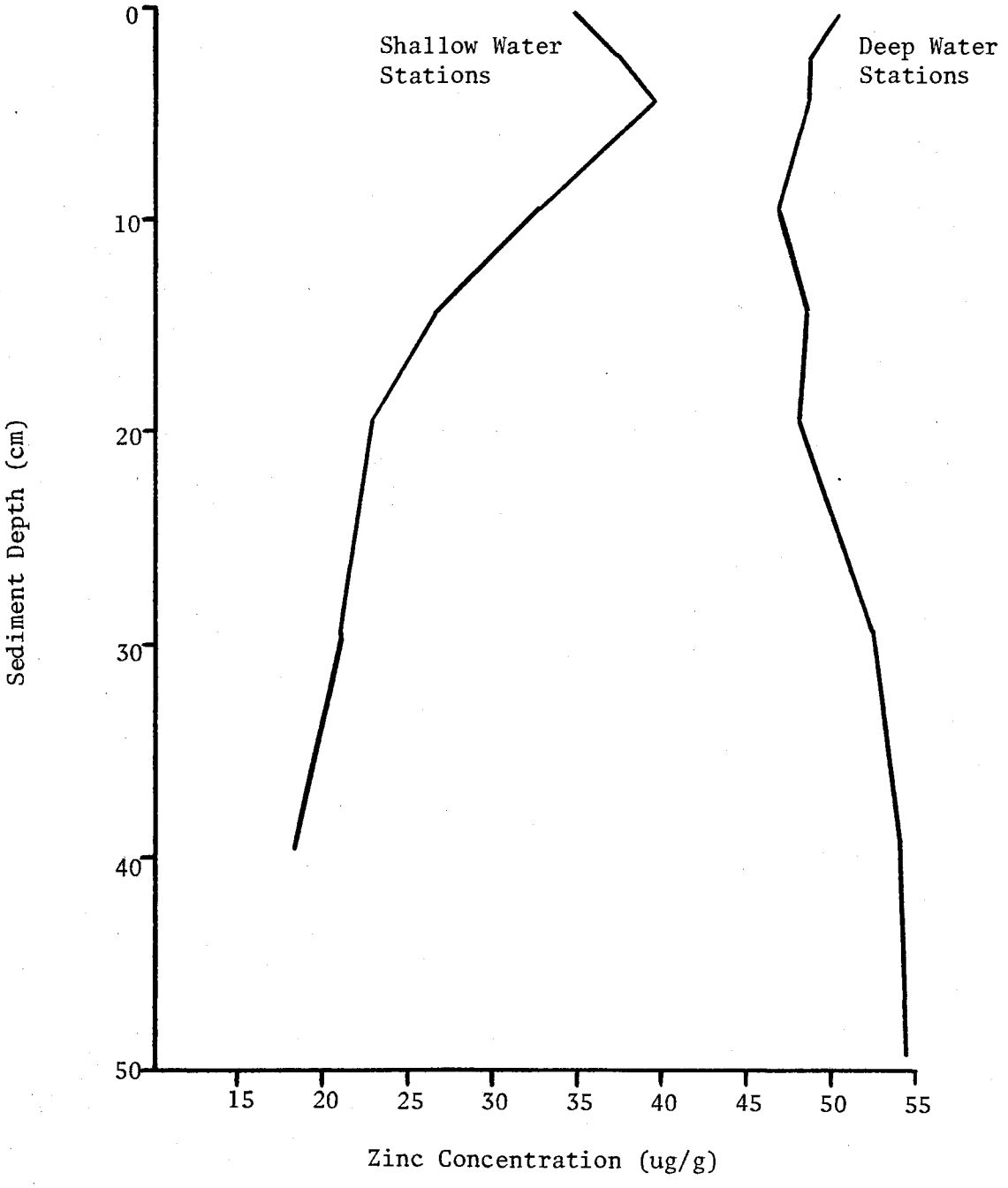

Figure 4. Zinc Concentrations in Shallow and Deep Water Sediments in Lake Carl Blackwell.

CHAPTER VII

DISCUSSION AND CONCLUSIONS

Copper, Lead, and Zinc in Water

Concentrations of copper in Lake Carl Blackwell water ranged from 2 to 17 ug/l and averaged 5 ug/l. The concentrations observed in Lake Carl Blackwell were within the range of concentrations found in other locations (Table III). The mean concentration in Gilbert Stuart Pond, Rhode Island, was 0.6 ug/l (Corless 1968) and was 1.1 ug/l in the Illinois River near Peoria (Mathis and Cummings 1971). Copper concentrations in the Monongahela River at Pittsburg ranged from 3 to 280 ug/l with a mean of 66 ug/l (Kopp and Kroner 1968). The Illinois and Monongahela receive large quantities of industrial wastes. Copper concentrations in Lake Carl Blackwell were well below the level of 1000 ug/l required for drinking water by the United States Public Health Service (Hem 1970).

The range and mean concentration of lead in Lake Carl Blackwell water were 1 to 8 ug/l and 3 ug/l, respectively. The concentrations in Lake Carl Blackwell were of the same magnitude as those reported in the literature (Table III). A mean concentration of 0.5 ug/l was reported for 170 High Sierra Lakes (Bradford et al. 1968). The mean concentration of lead in Ohio River water collected from an area receiving industrial wastes

was 56 ug/1 (Kopp and Kroner 1968). Lead concentrations in surface and ground waters used for domestic supplies range from traces to 40 ug/1 with a mean of approximately 10 ug/1 (Kopp and Kroner 1968). A level of 50 ug/1 is the maximum allowed for drinking water by the United States Public Health Service (Hem 1970).

Zinc concentrations in Lake Carl Blackwell water ranged from 2 to 97 ug/1; the mean was 20 ug/1. Considerable variation exists in zinc content of water in other locations (Table III). Mean concentrations of only 0.6 ug/1 and 1.5 ug/1 were reported for the Newport River Estuary (Cross et al. 1970) and 170 High Sierra Lakes (Bradford et al. 1968). In contrast, water samples from 37 locations across the United States had a mean content of 136 ug/1 (Kehol et al. 1944). Water from a highly industrialized section of the Saale River, Germany, contained concentrations of zinc ranging from 116 to 332 ug/1. The United States Public Health Service standard for drinking water is 5000 ug/1 (Hem 1970).

Finally, it is unlikely that the concentrations of copper, lead, or zinc in Lake Carl Blackwell are high enough to have any toxic effects on the aquatic biota. All of the concentrations observed in Lake Carl Blackwell were well below levels reported to be toxic. The 96-hour TLm for a fresh water snail (Physa heterostropha) was 790 to 1270 ug/1 zinc (Patrick and Sheier 1968). The mean zinc concentration of Lake Carl Blackwell water was only 20 ug/1. A copper concentration of 1250 ug/1 was reported as the 96-hour TLm for the bluegill (Lempomis macrochirus) (Cairns and Scheier 1968). The mean concentration observed in Lake Carl Blackwell water was only 5 ug/1.

Copper, Lead, and Zinc in Sediment

The copper content of Lake Carl Blackwell sediment was low in the range of values reported in the literature (Table III). A mean concentration of 11.8 ug/g was observed in Lake Carl Blackwell. The mean content of Mississippi River sediments was 10 ug/g (Morris et al. 1972). Mean copper concentrations of the sediments were as high as 39 ug/g in Lake Michigan (Shimp et al. 1971) and 102 ug/g in Tasman Bay, New Zealand (Brooks and Rumsby 1965).

Considerable variation exists in vertical distribution of copper in sediments. In Lake Michigan, copper concentrations tended to decrease with increasing depth of sediment (Shimp et al. 1970). Mean copper concentration decreased from 41 ug/g in surface sediments to 20 ug/g in sediments 16 cm and deeper (Shimp et al. 1971). In sediments of Lake Monona, Wisconsin, copper increased from 230 ug/g to 650 ug/g in the first 60 cm but then decreased to 30 ug/g at a depth of 100 cm (Bartleson 1971 after Sanchez 1970). In Lake Carl Blackwell, vertical variation was related to water depth. The copper content of shallow water sediment in Lake Carl Blackwell decreased with depth, from 10.9 ug/g in surface sediments to 4.4 ug/g at a depth of 39 to 40 cm (Figure 2). In contrast, in deep water stations copper increased slightly from 13.5 ug/g at the interface to 15.8 ug/g at the 49 to 50 cm depth.

The concentrations of lead found in Lake Carl Blackwell sediment were within the range of values in the literature (Table III). Concentrations ranged from 4.6 to 53.8 ug/g in Lake Carl Blackwell

and averaged 25.0 ug/g. Sediment collected in Tasman Bay, New Zealand, contained less than 5 ug/g lead (Brooks and Rumsby 1965). The mean concentration of lead in the Mississippi River was 14 ug/g (Morris et al. 1972). In contrast, sediment from the English Lake District had a mean content of 475 ug/g (Gorham and Swaine 1965).

No consistent pattern exists in vertical stratification of lead in sediments. In the English Lake District, mean lead concentrations increased from 425 to 550 ug/g in the first 10 cm (Gorham and Swaine 1965). In contrast, lead content of all samples collected in Lake Michigan decreased with sediment depth (Shimp et al. 1970). Lead content of one core decreased from 90 ug/g to 19 ug/g in the first 6 cm but then increased only 1 ug/g in the next 80 cm. Mean lead content of interface sediments was 79 ug/g in Lake Michigan (Shimp et al. 1971). The concentration decreased to 20 ug/g in sediments of 16 cm and deeper. Lead content of Lake Carl Blackwell shallow water sediments increased from 20.9 to 23.3 ug/g in the first 5 cm and then decreased to 4.6 ug/g at a depth of 39 to 40 cm (Figure 3). Lead content of deep water sediments was relatively uniform over depth.

A wide range of zinc concentrations has been found in sediments (Table III). A range of 8.6 to 86.1 ug/g was observed in Lake Carl Blackwell. The mean zinc concentration was 42.1 ug/g. A mean concentration of 0.6 ug/g was observed in the Newport River sediment estuary (Cross et al. 1970). The upper 15 cm of sediment contained 10 to 18 ug/g in Redfish Bay, Texas (Parker 1962). Sediment of the Potomac River near Harpers Ferry, West Virginia, had a mean concentration of 400 ug/g (O'Connor et al. 1964).

Considerable variation exists in vertical distribution of zinc in lake sediments. In Lake Windermere, England, zinc concentrations increased in the first 10 cm (Gorham and Swaine 1965). However, in nearby Lake Esthwaite there was no change or a decrease in zinc content over the first 10 cm. Zinc concentrations in Lake Michigan sediment decreased with depth in 3 of 4 cores (Shimp et al. 1970). At one station in the west-central part of the lake the concentration decreased from 179 to 42 ug/g in only 6 cm. In another study mean concentrations of zinc decreased from 179 ug/g in surface samples to 66 ug/g at a depth of 16 cm and deeper (Shimp et al. 1971). Shallow water sediments in Lake Carl Blackwell increased from 35.1 to 38.5 ug/g in the first 5 cm, but decreased to 18.4 ug/g at a depth of 39 to 40 cm (Figure 4). Deep water sediments increased slightly from 50.3 in surface sediments to 54.4 ug/g at the 49 to 50 cm depth.

The vertical stratification of metals in the sediment was different in shallow water areas than in deep water areas of Lake Carl Blackwell (Figures 2, 3, and 4). The concentrations of all three metals were higher in deep water sediments than in shallow water sediments. More importantly, metal concentrations at deep water stations were relatively uniform over sediment depth, while at shallow water stations concentrations decreased with sediment depth. It is possible that in shallow water areas of the lake the sediment was frequently resuspended by wind-driven wave action (Norton 1968). As the sediment was redeposited the larger sand and silt particles were deposited first. Because of the larger surface area/volume ratio associated with clay

particles, there is greater area to which heavy metal ions can adhere. Thus, more heavy metals were deposited in the upper layers of sediments with clay particles than in the deeper layers with sand and silt particles. This also explains why deep water stations had higher but more uniform concentrations of copper, lead, and zinc. Larger quantities of clay particles were transported into deep water, thus carrying with them more heavy metal ions. Sand and silt particles, however, were deposited in shallow water. The clay particles, once deposited, were undisturbed because of the depth of the water.

In the uppermost 5 cm of shallow water sediment there was a slight decrease in concentrations of lead and zinc. Water collected from the sediment interface had higher metal concentrations than water collected from the surface of the lake. These facts indicate that there was a transition zone in the upper sediment where metals moved from the sediment into the water.

CHAPTER VIII

SUMMARY

The overall mean concentrations of copper, lead, and zinc in the water of Lake Carl Blackwell were 5, 3, and 20 ug/l, respectively. All concentrations observed were far below the maximum levels permitted in domestic water supplies by the United States Public Health Service. No statistical difference was found in metal content of the water between deep water and shallow water areas of the lake. The difference between metal content of water collected at the surface and water collected at the sediment interface was statistically significant. Also statistically significant was the difference in metal content of the water over time. Highest concentrations occurred after a period of rainfall, indicating that runoff contributed to the metal content of the water.

The mean copper, lead, and zinc content of deep water sediments was 12.9, 30.7, and 48.5 ug/g respectively. In contrast, the mean content of shallow water sediments was 10.1, 19.5, and 34.1 ug/g. The difference between deep and shallow water areas was statistically significant. Metal concentrations in shallow water sediments generally decreased with increasing sediment depth. In contrast, metal content of deep water sediments was relatively uniform over depth. This suggests that wind driven

currents that keep the bottom well circulated in shallow areas are responsible for redistribution of trace metals. Clay particles, which provide greater surface area than sand or silt particles to which heavy metal ions can adhere, are frequently resuspended. Because the clay particles are held in suspension longer, they are redeposited in upper layers, thus, increasing the metal concentration of surface sediments. Statistically significant variation in the metal content of the sediment over time existed. Highest concentrations were observed after the area had received a heavy rain. This indicates that metals in runoff which contributed to the lake water soon moved into the sediment.

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APPENDIX

COPPER CONCENTRATIONS IN LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	19-20	16.0**	14.9	14.6	12.7	15.2	14.7
	29-30	16.3	15.2	16.7	10.6	14.2*	14.7
	39-40	15.2	14.7	16.1	8.0	13.1	13.4
	49-50	16.0	14.0*	17.0	-	7.8	13.6
II	19-20	14.5	16.0	18.6	15.8	16.4	16.3
	29-30	15.4	17.6	17.0	14.9	15.0*	16.1
	39-40	15.5	16.6	17.6	14.1	17.2	16.2
	49-50	14.3*	17.4	17.6*	14.1*	17.6	16.6
III	19-20	6.3	17.8	11.8	3.8	5.9	9.1
	29-30	-	15.4	6.3*	-	-	12.4
	39-40	-	14.4	-	-	-	14.4
	49-50	-	17.1	-	-	-	17.1
IV	19-20	6.6	5.9	5.3	4.7	8.1	6.1
	29-30	6.7	-	-	3.8*	-	5.7
V	19-20	7.3	6.3	5.8	3.4	5.4	5.6
	29-30	6.8*	5.3	6.4	3.0*	7.1*	5.8
VI	19-20	9.9	14.6	10.4	11.9	6.3	10.6
	29-30	11.1	7.3	6.8	9.1	-	8.6
	39-40	-	-	6.1*	4.9	-	5.3
VII	19-20	6.2*	6.6	7.6	4.7	7.3	6.5
	29-30	-	-	-	6.1*	-	6.1

APPENDIX (Continued)

LEAD CONCENTRATIONS IN LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	19-20	37.3	39.0	34.3	41.5	31.1	36.6
	29-30	36.1	43.5	38.1	25.9	12.1*	33.3
	39-40	36.2	36.7	39.3	20.8	23.0	31.2
	49-50	34.3	33.7*	38.1	-	8.5	27.9
II	19-20	30.4	40.7	41.1	52.8	34.6	39.9
	29-30	31.0	45.2	41.9	49.6	33.0*	40.9
	39-40	31.5	42.4	40.0	42.4	32.1	37.7
	49-50	27.2*	38.1	41.1*	36.5*	35.4	36.0
III	19-20	5.6	42.8	19.0	8.1	8.1	16.7
	29-30	-	33.4	4.2*	-	-	23.7
	39-40	-	31.4	-	-	-	31.4
	49-50	-	32.0	-	-	-	32.0
IV	19-20	8.1	9.4	6.2	12.0	8.0	8.7
	29-30	8.1	-	-	9.2*	-	8.4
V	19-20	6.8	6.7	5.8	4.1	5.8	5.8
	29-30	5.0*	6.7	6.2	4.0*	5.9*	5.8
VI	19-20	14.5	23.3	16.4	23.8	5.0	16.6
	29-30	8.4	6.8	5.9	12.2	-	8.3
	39-40	-	-	7.7	3.1	-	4.6
VII	19-20	7.1*	8.3	7.1	4.9	7.1	6.9
	29-30	-	-	-	8.9*	-	8.9

APPENDIX (Continued)

ZINC CONCENTRATIONS IN LAKE CARL BLACKWELL SEDIMENT

Station	Depth (cm)	Date 9/9	9/14	9/26	9/30	10/7	$\bar{x}$
I	19-20	54.2	49.2	53.2	51.0	52.1	51.9
	29-30	53.7	62.3	59.3	39.5	36.7*	51.8
	39-40	51.3	52.1	58.7	33.4	40.8	47.2
	49-50	52.4	57.8*	58.5	-	22.9	46.5
II	19-20	50.2	62.9	66.9	69.9	73.2	64.7
	29-30	53.7	69.9	60.5	66.2	77.3*	64.2
	39-40	53.6	62.8	59.0	61.4	66.9	60.7
	49-50	39.3*	63.4	59.8*	70.6*	60.3	59.6
III	19-20	11.2	57.8	37.5	15.3	16.2	27.6
	29-30	-	52.2	18.0*	-	-	42.8
	39-40	-	53.7	-	-	-	53.7
	49-50	-	57.1	-	-	-	57.1
IV	19-20	15.4	17.1	14.8	16.0	23.3	17.3
	29-30	11.7	-	-	18.3*	-	13.9
V	19-20	20.1	19.3	16.9	16.2	20.4	18.6
	29-30	13.6*	16.8	16.0	12.8*	18.6*	15.8
VI	19-20	27.6	40.6	35.9	51.7	17.3	34.6
	29-30	26.4	20.1	43.9	40.6	-	32.8
	39-40	-	-	16.6*	19.4	-	18.4
VII	19-20	22.1*	18.0	24.4	18.0	24.4	21.3
	29-30	-	-	-	21.4*	-	21.4

* -single observation, others are mean of two observations.

** -all values expressed as ug/g dry weight of sediment.

VITA 2

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